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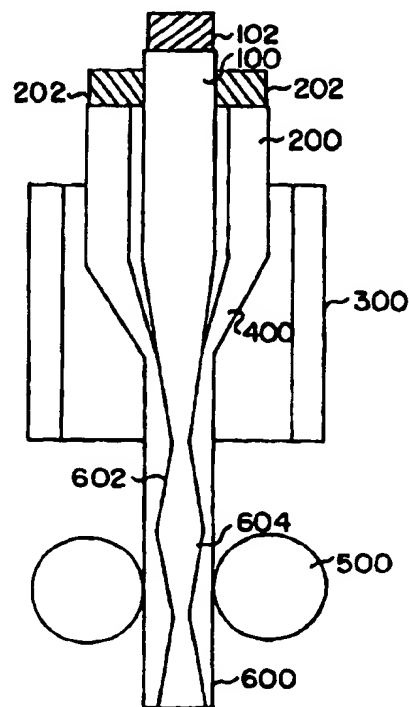
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(54) Title: METHOD OF MAKING DISPERSION DECREASING AND DISPERSION MANAGED OPTICAL FIBER

## (57) Abstract

The invention is a method of making an optical fiber or cane (600) that has optical properties that vary axially. Core glass (100) and clad glass (200) are fed into a furnace to form the cane or fiber. The velocities of the feeding of the clad and core are controlled so that the total combined mass per unit time is constant. The diameter of the core (604) varies along the length of the fiber or cane in accordance with the control of the velocities. The variance in the core diameter results in the variance of the axial optical properties of the fiber or cane.



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METHOD OF MAKING DISPERSION DECREASING  
AND DISPERSION MANAGED OPTICAL FIBER

Background of the Invention

5           This invention relates to methods of making  
optical fiber having longitudinally varying optical  
properties. Optical fibers made in accordance with the  
invention may include dispersion decreasing and  
dispersion managed fiber. Such fibers may be used for  
soliton pulse transmission, in which an optical soliton  
10       pulse maintains its original shape as it travels along  
the optical fiber. However, the invention is not  
limited to this application.

          Dispersion refers to the spreading out of light  
pulses as they travel in an optical fiber. Such  
15       spreading of a soliton pulse causes attenuation losses  
as the pulse travels along the fiber. Dispersion may be  
compensated for by changing the optical properties of  
the fiber so as to reduce the total dispersion. Two  
types of fiber which compensate for dispersion are  
20       dispersion decreasing fiber and dispersion managed  
fiber.

          Dispersion decreasing fiber has a slow change in  
dispersion over the length of the fiber. This gradually  
decreases the dispersion in the fiber and thus decreases  
25       the effect of attenuation losses on the transmission of  
a soliton pulse traveling along the fiber.

          Dispersion managed fiber is characterized by  
sections of positive and negative dispersion, with

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relatively sharp transitions between each section. Dispersion managed fiber strives to create a fiber where the overall dispersion of the fiber is zero, but the dispersion at any one point is either slightly positive or negative. Such a scheme minimizes the effects of four-wave mixing, self phase modulation and other nonlinear optical effects that are produced by transmitting data pulses at the zero dispersion point, while still effectively compensating for the chromatic dispersion effects that occur over the length of the fiber link.

The present invention is directed to methods of making dispersion decreasing and dispersion managed fiber by axially changing the optical properties of the fiber.

Prior art methods of making fiber, having axially changing optical properties, each have associated disadvantages. For example, changing the core-clad ratio, by either machining or chemically etching the consolidated preform or core cane, alters the optical properties of the fiber. Unfortunately, this method adds additional processing steps and additional select losses associated with these steps. Changing the draw tension may also change the optical properties of the fiber axially, but, this method fails to maintain the advantages of drawing fiber in a particular tension regime. Another alternative, altering the optical properties of the fiber by drawing a fiber having a non-constant outer diameter, creates unwanted connectorization and splicing issues. Theoretically, the optical properties of the fiber can be changed by placing multiple overclad compositions on the fiber to obtain stress effects in the drawn fiber. However this method would alter the existing laydown and consolidation processes to such an extent that it would

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not likely provide a viable manufacturing process.

Thus, there is a need for a method of changing the optical properties of fiber that does not have the disadvantages associated with these prior art methods.

5      Summary of the Invention

          It is an object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber without additional manufacturing steps or the select losses associated with such additional steps.

10           It is a further object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber which maintains a particular tension regime during the draw process.

15           It is an object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber having a constant outside diameter.

          It is a further object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber which does not alter existing laydown and consolidation processes.

20           It is an object of the present invention to provide a method of making dispersion decreasing and dispersion managed fiber which allows the axial location of change in the dispersion in the fiber to be determined.

          The disadvantages and limitations of other methods of changing the optical properties of fiber are overcome by the present invention, which provides a method for separately controlling and varying the input, into a furnace, of core and clad material, and thereby controlling the core diameter of the product which exits

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the furnace, i.e. either core or fiber, e.g. by drawing a rod and tube simultaneously using separate downfeeds.

#### Brief Description of the Drawings

5 The above and other objects and advantages of the invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which like reference characters refer to like parts throughout, and in which:

10 FIG. 1 is a diagram showing an illustrative embodiment of a method of making Dispersion Decreasing and Dispersion Managed Fiber in accordance with the present invention; and

FIG. 2 is a block diagram of a control system of the present invention.

#### 15 Detailed Description of the Invention

The method of the present invention includes mounting (1) a rod containing core glass and possibly a material amount of cladding glass, and (2) a tube of cladding glass, on separate downfeeds going into a draw furnace such that the rod is within the tube. (As those skilled in the art will recognize, "core" glass has a higher refractive index than "clad" glass.) The rod and tube are lowered through the furnace and combine to form a fiber which is drawn from the furnace. The velocity of each downfeed is separately controlled and coordinated such that the mass per unit time of glass passing through the furnace remains constant, while at the same time varying the amount of rod and tube material passing through the furnace.

30 The resultant fiber (or cane) drawn from the furnace has a constant outside diameter. However, the diameter of the core of the fiber varies along the length of the fiber in accordance with the variance of

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the amount of tube or rod material passing through the furnace. It is the resulting variance in the core diameter of the fiber which provides axial variation of the optical properties of the fiber.

5           In making dispersion decreasing fiber, the variance in the diameter of the core is very gradual, to allow for a slow change in dispersion along the length of the fiber. The making of dispersion managed fiber requires more abrupt changes in the diameter of the core  
10       of the fiber to create sections of positive and negative dispersion fiber with relatively sharp transitions between each section. Both gradual and abrupt changes in the core diameter of the fiber may be obtained through the process of the present invention.

15           FIG. 1 is a generalized illustration of the fiber drawing process of this invention. The rod 100, consisting of all core material and possibly a material amount of cladding is mounted on a downfeed 102. The tube 200, which consists entirely of cladding glass, is  
20       mounted on a separate downfeed 202. The clad glass of the tube 200 may be pure silica. A control system 204 may be operated manually or automatically to control the velocity of the downfeeds 102 and 202. The control system 204 includes a programmable controller which  
25       includes two motors (not shown), in which the first motor is connected to downfeed 102 and the second motor is connected to downfeed 202. The control system 204, with the use of the motors, controls the velocity of the downfeeds 102 and 202. In controlling the velocity of  
30       the downfeeds 102 and 202, the control system 204 insures that the mass per unit time of glass passing through the furnace remains constant, while at the same time varying the amount of rod 100 and tube 200 passing through the furnace 300. The programmable computer is  
35       programmed with the desired variation of the core

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diameter, as a function of fiber length, and receives a feedback signal from the fiber draw system representing draw speed.

5 The rod 100 and the tube 200 combine in the furnace 300 to form a fiber or cane 600. Cane is thicker and sturdier than fiber, includes an inner core region and a surrounding clad and may later be overclad and drawn into fiber. My invention is applicable both to making fiber or cane. However, by way of  
10 illustration, my invention is primarily described herein with reference to making fiber. The fiber or cane 600 is drawn from the furnace by a set of tractors 500.

The principle of operation of the invention is as follows. At steady state, the total amount of glass  
15 going into the draw as rod 100 and tube 200 is equal to the amount of glass coming out as fiber 600. This can be represented by the following equation:

$$A_{rod}V_{rod} + A_{tube}V_{tube} = A_{fiber}V_{fiber}$$

where  $V_x$  = the velocity of the component x; and

20  $A_x$  = the cross sectional area of component x.

The diameter of the core of the fiber,  $D_{core}$ , may be described by the following equation:

$$D_{core} = D_{fiber} * Kf A_{rod}V_{rod} / (A_{rod}V_{rod} + A_{tube}V_{tube})$$

where  $D_{fiber}$  = fiber diameter;

25  $K$  = the ratio of the area of the fiber to the sum of the areas of the rod and the tube; and

$f$  = the ratio of the area of the core diameter to the outer diameter of the fiber.

30 The outside diameter of the fiber,  $D_{fiber}$ , may be described by the following equation:

$$D_{fiber} = 2 * \sqrt{\frac{(A_{rod}V_{rod} + A_{tube}V_{tube})}{V_{fiber}\pi}}$$



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Combining the equation for  $D_{core}$  and  $D_{fiber}$  gives the following expression for  $D_{core}$ :

$$D_{core} = \frac{2Kf A_{rod} V_{rod}}{\sqrt{V_{fiber}(A_{rod} V_{rod} + A_{tube} V_{tube})} \pi}$$

Each of the terms of this equation can be varied over time. Desirably, the dimensions of the rod and the tube, as they are fed into the furnace, remain constant. It is also desirable that the fiber drawn from the furnace has a constant outside diameter. Therefore, when these factors are constant,  $K$  and  $f$  are constants. An inspection of the equation for  $D_{fiber}$  shows that in order for  $D_{fiber}$  to remain constant while  $D_{core}$  varies, at least two of the terms must be varied. (Although constant outside diameter is not required for optical properties, it is a desirable attribute for cabling, connecting and splicing.)

Examination of the equation for  $D_{core}$  as a function of time shows that  $D_{core}$  can be varied in a variety of ways to obtain a fiber having a constant outside diameter. In theory, any two of the variables,  $A_{rod}$ ,  $A_{tube}$ ,  $V_{rod}$ ,  $V_{tube}$  or  $V_{fiber}$  could be modulated in such a way to produce a fiber having a constant outside diameter. This invention is directed towards those combinations of variables that do not require changing  $A_{rod}$  or  $A_{tube}$ . Using the approach of changing only draw speeds or downfeed speeds makes it possible to correlate changes in the fiber with changes in draw or downfeed speed, that would not be as easily done with changes in  $A_{rod}$  or  $A_{tube}$ .

Three possible combinations of velocities can be varied over time:  $V_{fiber}V_{rod}$ ,  $V_{tube}V_{rod}$ , and  $V_{fiber}V_{tube}$ . Varying  $V_{rod}V_{tube}$  while holding  $V_{fiber}$  constant requires that the mass per unit time of glass passing through the furnace

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be constant, so there is little or no change in the shape of the root 400 that is normally associated with changes in fiber draw speed. This minimizes unsteady state behavior and makes it easier to control the process. This approach also makes it easier to determine where the changes in the core diameter occur in a fiber by correlating changes in downfeed speed to the length of fiber drawn. There is some lag time between when the downfeed change is made and when the drawn fiber actually starts to change, but under the relatively steady state condition provided by holding  $V_{\text{fiber}}$  constant, this lag time is fairly constant. This also cuts down on waste which in turn makes the manufacturing of dispersion decreasing and dispersion managed fiber easier and more cost effective.

A block diagram of a control system which may be used in the present invention is set out in FIG. 2. The control system may be implemented using conventional components which perform the designated computational functions, e.g. a computer. In this control system,  $A_{\text{rod}}$ ,  $A_{\text{tube}}$ ,  $K$  and  $f$  are constants, as the chemical and physical composition of the rod and tube and their cross sectional dimensions, do not vary substantially along their length. The diameter of the fiber,  $D_{\text{fiber}}$ , is set based on the specification of the fiber. A typical value in telecommunication fibers is 125  $\mu\text{m}$ .  $V_{\text{fiber}}$  is set or controlled based on the capacity of the draw, and the ability to adequately control any secondary processes, such as coating application in the case of fiber. In general,  $V_{\text{fiber}}$  is set as high as possible, while still maintaining control of the process to maximize draw capacity. The value of  $D_{\text{core}}$  is determined based on the dispersion target for the particular fiber being made and is provided to the control system from the programmable computer. For example, to produce a

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dispersion decreasing fiber,  $D_{core}$  would be slowly decreased over a length of fiber tens of kilometers in length. To produce dispersion managed fiber, the core diameter would be increased and then decreased, as indicated in Fig. 1 by the core portions 602 and 604. The calculation determining the waveguide dispersion may be done separately from the actual control process or directly in the control loop by the determination of  $D_{core}$ . The calculation may also be incorporated into the control scheme in which case the waveguide dispersion would be an independent variable and  $D_{core}$  would depend on the waveguide dispersion. My invention allows the production of a fiber or cane having a core diameter which varies linearly or non-linearly as a function of length.

Once  $D_{fiber}$ ,  $V_{fiber}$  and  $D_{core}$  are established,  $V_{rod}$  is calculated from the following equation, which can be derived from the steady-state mass balance and the expression for  $D_{core}$  previously shown:

$$V_{rod} = \pi D_{fiber} V_{fiber} D_{core} / K f^2 A_{rod}.$$

Once  $V_{rod}$  has been determined,  $V_{tube}$  is calculated from the overall mass balance through the furnace:

$$V_{tube} = (V_{fiber} D_{fiber}^2 \pi - A_{rod} V_{rod}) / A_{tube}.$$

To produce a dispersion decreasing fiber  $D_{core}$  would be slowly decreased as the rod and tube were drawn into the fiber. As  $D_{core}$  is decreased,  $V_{rod}$  will be decreased by a factor of:

$$\pi D_{fiber} V_{fiber} / K f^2 A_{rod}.$$

At the same time,  $V_{tube}$  will increase by the factor  $A_{rod} / A_{tube}$ , thereby maintaining a constant mass balance in the furnace.

Similar control schemes may be used for the cases where  $V_{tube}$  is held constant and  $V_{fiber}$  and  $V_{rod}$  are varied, or where  $V_{rod}$  is held constant and  $V_{fiber}$  and  $V_{tube}$  are varied. In the case described above, it is also

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possible to reverse the calculation of  $V_{\text{tube}}$  and  $V_{\text{rod}}$ , such that  $V_{\text{tube}}$  is a function of  $D_{\text{core}}$  and  $V_{\text{rod}}$  is calculated from the mass balance.

5           Thus a method for creating dispersion decreasing  
and dispersion managed fiber is provided. Although  
particular illustrative embodiments have been disclosed,  
persons skilled in the art will appreciate that the  
present invention can be practiced by other than the  
disclosed embodiments, which are presented for purposes  
10 of illustration, and not of limitation, and the present  
invention is limited only by the claims that follow.

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## WHAT IS CLAIMED IS:

1. A method of making optical fiber or cane having a core and surrounding cladding, which comprises:  
supplying core glass material and cladding glass  
5 material to a furnace;  
varying the volumetric ratio of said core glass material to said cladding glass material passing through the furnace;  
combining said core glass material and said  
10 cladding glass material in the furnace; and,  
drawing from the furnace an optical fiber or cane which has a constant diameter.
2. The method of claim 1 wherein the optical fiber or cane is drawn at a constant speed.
- 15 3. The method of claim 2 wherein the diameter of the optical fiber or cane continuously decreases.
4. The method of claim 2 wherein the diameter of the optical fiber or cane continuously increases.
- 20 5. The method of claim 2 wherein the diameter of the core of the optical fiber or cane alternates between decreasing with length and increasing with the length of fiber or cane drawn.
6. A method of making optical fiber or cane having a core and surrounding cladding, which comprises:  
25 feeding core glass and cladding glass into a furnace;  
providing a signal representing a desired variation in the diameter of the core of the resulting fiber or cane in response to said signal;

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in response to said signal, varying the volumetric ratio of said core glass material to said cladding glass material passing through the furnace;

5 maintaining a constant volumetric flow of glass through the furnace;

combining said core glass material and said cladding glass material in the furnace; and,

drawing from the furnace an optical fiber or cane which has a constant diameter.

10 7. The process of claim 6 where said varying step is comprised of the steps of:

in response to said signal, varying the rate at which said core glass is feed into the furnace;

15 generating a second signal representative of the rate at which said core glass is feed into the furnace; and

in response to said second signal, varying the rate at which said clad glass is feed into said furnace.

20 8. The process of claim 6 where said varying step is comprised of the steps of:

in response to said signal, varying the rate at which said clad glass is feed into the furnace;

25 generating a second signal representative of the rate at which said clad glass is feed into the furnace; and,

in response to said second signal, varying the rate at which said core glass is feed into said furnace.

9. A method of making optical fiber or cane having a core and surrounding cladding, which comprises:

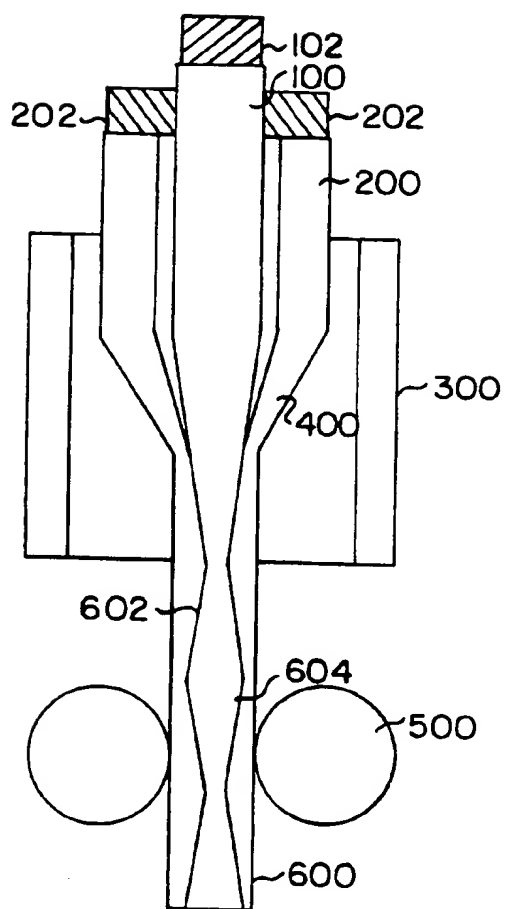
30 providing a glass tube which is comprised of cladding glass;

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providing a glass rod which comprised of core  
glass;  
placing said rod in said tube;  
attaching one end of said rod to a first drive  
5 means;  
attaching one end of said tube to a second drive  
means;  
lowering the other end of said rod and tube into a  
furnace;  
10 independently varying the rate of lowering of said  
rod and said tube into the furnace so that the ratio of  
rod material to tube material fed into the furnace  
varies;  
drawing an optical fiber or cane from said furnace  
15 which has a constant outer diameter and a varying core  
diameter.

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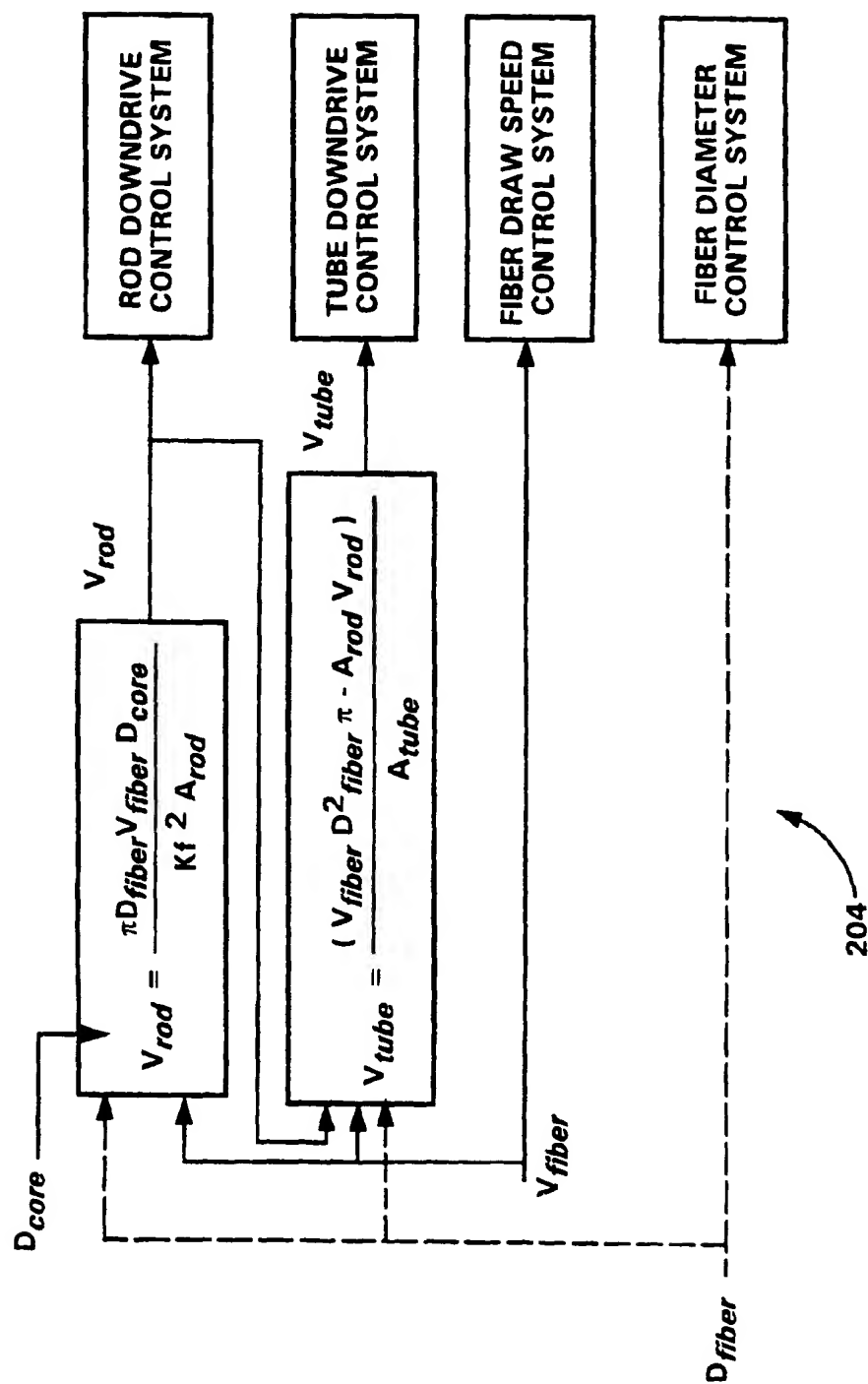
FIG. 1





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FIG. 2



## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US97/02163

**A. CLASSIFICATION OF SUBJECT MATTER**

IPC(6) : C03B 37/027, 37/07, 37/075

US CL : 65/381, 377, 402, 412

According to International Patent Classification (IPC) or to both national classification and IPC

**B. FIELDS SEARCHED**

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 65/381, 377, 402, 412

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y,E	US 5,613,028 A (ANTOS et al) 18 March 1997, col. 4, lines 21-40.	1,2,5-9
A	US 4,578,096 A (SIEGMUND) 25 March 1986.	
A	JP 405178634 A, (NAKAYAMA) 20 July 1993.	

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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